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EXPERIMENTAL INVESTIGATION OF THE EFFECT OF M-BAND PREHEATING IN INDIRECTLY-DRIVEN DOUBLE-SHELL IMPLOSIONS

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Experimental results are presented from several series of experiments studying the effect of 2-4 keV M-shell radiation on the implosion of double-shell capsules on the Omega Laser at the Laboratory for Laser Energetics. In the first series of experiments, precision machined double-shell capsules implosions are performed. A discrepancy is observed between the experimentally measured M-band fraction and the simulated value. The application of a time-dependent multiplier to the simulated M-band level results in a decrease in predicted yield of 35% and a corresponding increase in the YoC to 20-35%.

In order to further investigate this discrepancy, a series of "M-Band driven" targets has been designed. An oversized outer shell is used to preferentially allow the M-band radiation to drive the implosion of a CH-tamped glass inner shell. The inner shell radius-time history is measured and is shown to be consistent with the simulations using the time-dependent M-band multipliers.

The spatial distribution of this M-band source is also varied using hohlraums of different length and adjusting the laser pointing accordingly. The resulting asymmetry of the inner shell implosion is diagnosed both by x-ray backlighting prior to shell collision and by core emission.

I. INTRODUCTION

Indirectly-driven double-shell ignition targets are being investigated as a non-cryogenic path to ignition. In a double-shell target, a relatively more massive low-Z outer shell absorbs hohlraum-generated thermal x-rays and collides with a lower mass high-Z inner shell, imparting sufficient implosion velocity for volume ignition of the thermonuclear fuel. The primary function of the high-Z inner shell is to reduce radiative losses from the fuel, thus enabling lower implosion speeds. In early double-shell experiments with glass inner shells conducted on both Nova and Omega, the measured yield was only a small fraction of the calculated clean one-dimensional yield [1].

One of the reasons suggested in reference [1] for this poor performance was non-uniform preheat illumination by 2-4 keV M-shell radiation originating from the laser hot spots on the hohlraum wall. In order to investigate this possible mechanism, a series of double-shell experiments has been conducted on the Omega Laser at the Laboratory for Laser Energetics, University of Rochester. The result of these experiments is reported here.

II. THE EFFECT OF M-BAND RADIATION ON PRECISION DOUBLE SHELL IMPLOSIONS

In the first series of experiments, the implosion of a set of 5 precision-machined double-shell capsules meeting very stringent specifications on shell wall thickness uniformity and concentricity was performed (both better than 5 μm). These double-shell targets were designed [2] to exhibit ignition-like characteristics, meaning that the bulk of the yield is generated in the compressional phase of the implosion as opposed to that produced earlier at shock convergence. Capsules with two different inner shell wall thicknesses were used in these tests. The capsules consisted of a CH inner shell (inner radius = 106 μm, outer radius = 119 or 123 μm) filled with either 50 or 65 atm of deuterium (DD), respectively. The inner shell was centered between two precision-machined hemispheres of carbonized resourcinol formaldehyde (CRF) foam with a density of 50 mg/cc and a bulk pore size of 100 nm. The outer shell was made of two hemispheres of CH(2%Br) with an inner wall radius of 222μm and an outer wall radius of 275μm. A step joint, with a gap measured to be less than 2 μm, was machined in the outer hemispheres to accurately center and seal the capsule. These outer shell hemispheres were glued, and the excess glue was machined off to the final outer diameter.

The capsules were mounted using a very thin formvar web in standard Au hohlraums (75% LEH). The driving pulse shape was a reverse ramp in laser energy providing a nominal 16kJ of 3ω laser energy into the hohlraum. This pulse shape was designed to generate a relatively constant radiation temperature in the hohlraum. All 5 capsules performed well giving neutron yields ranging from 2.3-3.8 x 10^7. The ratio of the experimentally measured yield to the clean calculated 1D yield [2] is from 20-35%.

The radiation drive measured with DANTE [3-4] was found to be in good agreement with the simulations as shown in Figure 1(a). The same comparison for the highest energy channel of Dante (2-4 keV) vs. the simulations is shown in Figure 1(b). The dominant contribution in this energy range is from Au M-band radiation originating from the location of the laser hot spots on the hohlraum wall. The simulations are seen to seriously under-predict the radiation in this energy band. In order to accurately compare with the data, time-dependent multipliers are applied to the M-band fraction to match the simulated radiation drive to that of the experiments. The effect of this change in the radiation drive on the capsule yield is considerable. The addition of the M-band multipliers drops the clean 1D yield by approximately 30%. Complete details of the simulations are given in [2].

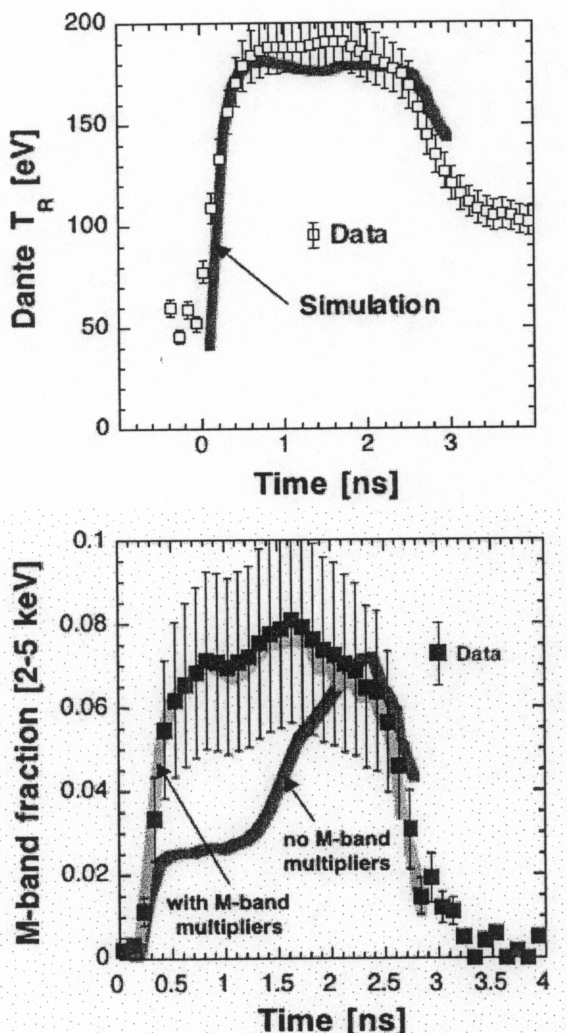


Figure 1: (a) Comparison of DANTE measured radiation drive from shot #31551 with simulations. (b) Comparison of measured Dante M-band fraction with simulated M-band fraction (with and without time-dependent multipliers applied).

In addition to affecting the 1D yield of these implosions, the spatial asymmetry of the M-band radiation source in the hohlraum is also important. This was studied in these experiments by comparison of the shape of the core emission of the precision-machined double-shells with equivalent results for 4 single-shell surrogate capsules which used the same radiation drive and laser pointing. These capsules had a single CH(2% Ge) shell with an inner radius of 227 μm and an outer radius of 275 μm, the same as that of the double-shells. The gas fill was 20 atm of DD. The yield of these capsules was slightly higher than that for the double-shells, ranging from $4.6 \times 10^7 - 1.5 \times 10^8$.

In order to enhance the core emission, argon was added to the DD fuel of both the single-shell and one of the double-shell capsules at a level of 0.1% to provide an enhanced signal for imaging of the shape of the core emission. This emission was imaged with a gated x-ray framing camera with a spatial resolution set by the imaging pinhole of 10 μm and a temporal resolution of 70 ps.

The resulting core shapes at peak emission are shown in Figure 2 for both (a) the single-shell and (b) the double-shell capsules. The hohlraum axis of symmetry in these images is horizontal. The single-shell core shape is seen to be very round, whereas the double-shell core shape is elongated along the hohlraum axis with an ellipticity ratio of 0.6. In addition, the double-shell core shape is bifurcated with two distinct emission lobes along the hohlraum axis. The laser drive and pointing was nominally the same for both of these implosions, indicating that the double-shell is seeing a different drive symmetry than the single-shell. This is believed to originate from the spatial asymmetry of the M-band source, which is a finite number of laser hot spots on the hohlraum wall.

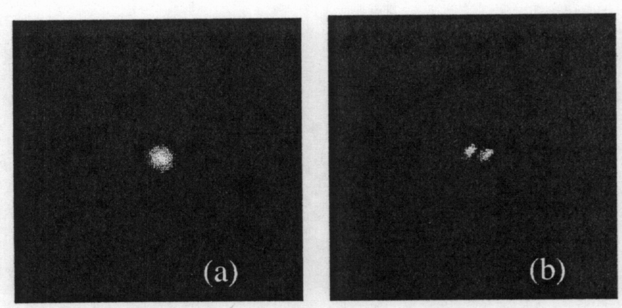


Figure 2: Core emission images of (a) single-shell capsule and (b) double-shell capsule.

III. IMAGING RESULTS FROM "M-BAND DRIVEN" SYMMETRICAL IMPLOSIONS

In order to further investigate the role of M-band in both the 1D implosion characteristics as well as the 2D implosion symmetry, an additional series of experiments was performed. These implosions used double-shell capsules, which were considerably simpler in their fabrication. No gas fill was used in these shots, as the primary goal was to study the effect of M-band radiation on the resulting implosion and asymmetry of the inner shell, which was diagnosed both by x-ray backlighting prior to shell collision and by core emission at minimum volume.

The inner shell to be imaged was a glass capsule with an inner radius of 120 μm and wall thickness of 8.4 μm. This was coated with 9.9 μm of CH, giving a total inner shell wall thickness of 18.3 μm. The CH layer acts as a tamper to suppress the outward expansion of the glass shell as it absorbs the M-band radiation. This composite inner shell was mounted in the hohlraum using a very thin formvar tent.

The outer shell was made of 1.4% Ti-doped CH with an inner radius of 352 μm and a wall thickness of 29.1 μm. This shell was assembled from two matching hemispheres, which were centered and glued on either side of the formvar tent holding the inner shell. The primary purpose of the outer shell in these implosions is to filter out the thermal x-rays and allow the M-band radiation to provide the dominant drive for the implosion of the CH-tamped glass inner shell.

The implosion of the inner shell was diagnosed with a Cr backlighter foil mounted over a 400 μm diameter hole in the hohlraum wall. This backlighter was irradiated with an additional set of 8 Omega beams, producing 6.2 keV x-rays to diagnose the implosion. The resulting absorption images of the inner shell were analyzed to give the average shell radius vs. time during the early part of the implosion prior to shell collision. The measured inner shell radius is plotted in Figure 3 together with the simulated radii produced by both the normal M-band drive fraction and the enhanced M-band drive with the same time-dependent multipliers that were used to match the data in Figure 1(b).

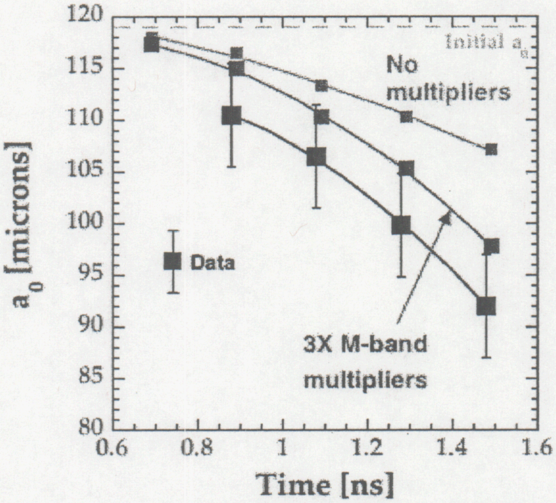


Figure 3: Inner shell radial position vs. time for "M-band driven" implosion, shot #31549. The simulated shell radial location is plotted both with and without time-dependent multipliers.

The enhanced drive is seen to give better agreement with the data than the simulation without the M-band multipliers. This experiment provides an independent measurement of the M-band drive strength, supporting the earlier observation that the code is under-predicting this portion of the radiation drive.

IV. RESULTS FROM AN "M-BAND DRIVEN" CONTROLLED ASYMMETRY EXPERIMENT

The spatial asymmetry of the M-band source was studied in a similar experimental configuration. Similar imaging capsules using the same fabrication process were again used with no DD gas fill. In order to controllably study the spatial origin of the M-band source, the capsules were mounted in hohlraums of different lengths. The hohlraums used were either standard cylindrical hohlraums (2.5 mm x 1.6 mm diameter), shortened hohlraums (2.1 mm x 1.6 mm diameter), or elongated hohlraums (2.9 mm x 1.6 mm diameter). Identical double-shell capsules were mounted in each, with the laser pointing adjusted to correspond to the hohlraum length. For the shortened hohlraums, the pointing of all three cones of beams was moved inward along the hohlraum axis by 400 μm. For the elongated hohlraums, the laser pointing was moved outward by 400 μm from the nominal pointing. This change in laser pointing moves the origin of the M-band radiation relative to the capsule centered in the hohlraum.

The resulting asymmetry of the inner shell implosion was diagnosed both by x-ray backlighting prior to shell collision and by core emission at minimum volume. Figure 4 shows a backlit image of both the inner and outer shells just prior to shell collision for the case of an elongated hohlraum. The hohlraum axis is tilted as shown in the Figure. The inner shell is seen to be imploding asymmetrically with a faster velocity along the hohlraum axis than that transverse to this axis.

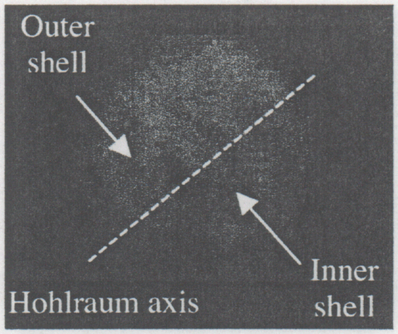


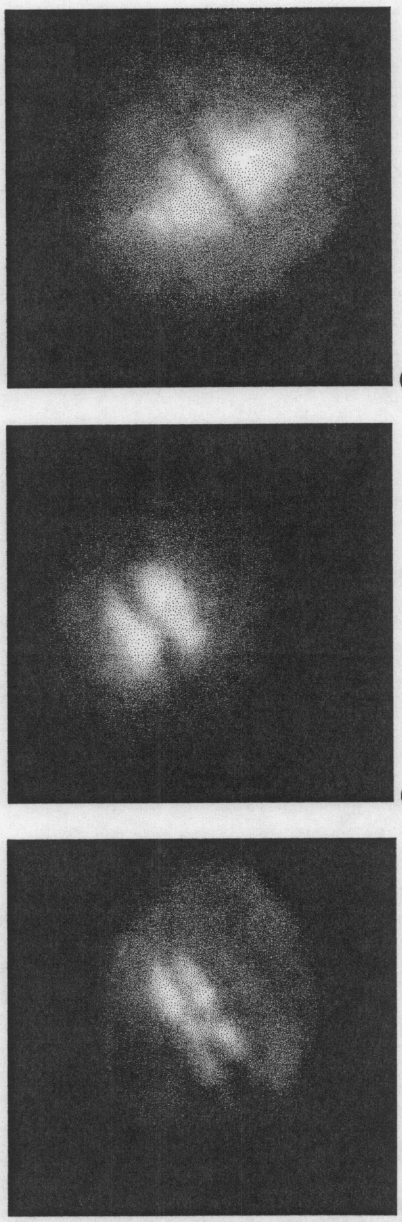
Figure 4: Backlit image of imploding shells for an elongated hohlraum.

The effect of this drive asymmetry is also seen in the shape of the resulting core emission at the time of minimum volume. Images of the core shape were obtained for implosions in all three hohlraums, again using a gated x-ray framing camera with a spatial resolution of 10 μm. Figure 5 shows the shape of the core emission for capsule implosions in (a) a shortened length hohlraum, (b) a standard length hohlraum, and (c) an elongated hohlraum. In all cases the x-ray pattern of the backlighter is still seen. The core shapes change from one that is elongated along the hohlraum axis for the short hohlraum (where the origin of the M-band drive is closer to the capsule waist) to one that is reasonably symmetrical for the standard hohlraum to one that is strikingly pancaked along the hohlraum axis for the elongated hohlraum (M-band drive is closer to the capsule poles).

Note that in all images there is a dark absorption feature in the center of each image, oriented perpendicular to the hohlraum axis.

This is thought to be a result of the manufacturing process for these simple double-shell targets, where the outer shell hemispheres are simply glued to the formvar tenting material. This forms a seam, which is oriented perpendicular to the hohlraum axis.

These experiments clearly show that the spatial location of the M-band radiation source is indeed well correlated with the location of the laser spots on the hohlraum wall. This indicates the importance in double-shell implosions of controlling both the magnitude of the M-band radiation and its spatial distribution within the hohlraum.



(a) (b) (c)

Figure 5: Core emission images of double-shell imaging capsules in (a) a shortened length hohlraum, (b) a standard length hohlraum, and (c) an elongated hohlraum.

V. CONCLUSIONS AND FUTURE DIRECTIONS

The results shown here present a consistent picture of the role of Au M-band preheating on indirectly-driven double-shell implosions. The double-shell implosions are found to be very sensitive to this preheating both in the 1D implosion characteristics as well as in the 2D symmetry of the implosion.

As double-shell designs move toward the use of inner shells made of the higher-Z materials [5,6] that will be required for ignition capsules on the NIF, this problem will become even more important. Future efforts will be directed at reducing the strength of the M-band source and its effect on capsule performance through improvements in capsule design of both inner and outer shells.

VI. ACKNOWLEGDEMENTS

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